METHODS FOR ADMINISTRATION OF ANTIBIOTICS

This application claims the benefit of U.S. Provisional Application Nos. 60/101,828, filed September 25, 1998, and 60/125,750, filed March 24, 1999, both of which are herein incorporated by reference.

TECHNICAL FIELD OF THE INVENTION

The present invention relates to improved methods of administering lipopeptide antibiotics, such as daptomycin, with potent bactericidal activity against gram-positive bacteria, including antibiotic-resistant strains. The present invention also relates to improved methods of administering quinopristin/dalfopristin, which also has potent bactericidal activity against gram-positive bacteria, including antibiotic-resistant strains.

BACKGROUND OF THE INVENTION

The rapid increase in the incidence of gram-positive infections—including those caused by resistant bacteria—has sparked renewed interest in the development of novel classes of antibiotics. One such class is the lipopeptide antibiotics, which includes daptomycin. Daptomycin has potent bactericidal activity *in vitro* against clinically relevant gram-positive bacteria that cause serious and life-threatening diseases. These bacteria include resistant pathogens, such as vancomycin-resistant enterococci (VRE), methicillin-resistant *Staphylococcus aureus* (MRSA), glycopeptide intermediary susceptible

Staphylococcus aureus (GISA), coagulase-negative staphylococci (CNS), and penicillin-resistant *Streptococcus pneumoniae* (PRSP), for which there are very few therapeutic alternatives (see Tally et al., 1999, Exp. Opin. Invest. Drugs 8:1223-1238, hereafter "Tally"). Daptomycin provides a rapid, concentration-dependent bactericidal effect and a relatively prolonged concentration-dependent post-antibiotic effect *in vivo*.

Daptomycin is described in Baltz in Biotechnology of Antibiotics, 2nd Ed., ed. by W.R Strohl (New York: Marcel Dekker, Inc.), 1997, pp. 415-435, hereafter "Baltz." Daptomycin is a cyclic lipopeptide antibiotic that can be derived from the fermentation of *Streptomyces roseosporus*. It is comprised of a decanoyl side chain linked to the N-terminal tryptophan of a cyclic 13–amino acid peptide (see Fig. 1a, Baltz et al., *supra*). The compound is currently being developed in both intravenous and oral formulations to treat serious infections caused by bacteria, including, but not limited to, methicillin resistant *Staphylococcus aureus* (MRSA) and vancomycin resistant enterococci (VRE).

Daptomycin's mechanism of action is distinct from that of other classes of antibiotics, which include β-lactams, aminoglycosides, glycopeptides and macrolides. Without wishing to be bound by any theory, daptomycin is believed to kill gram-positive bacteria by disrupting multiple aspects of bacterial plasma membrane function while not penetrating into the cytoplasm. The antibacterial mechanisms of daptomycin may include inhibition of peptidoglycan synthesis, inhibition of lipoteichoic acid synthesis and dissipation of bacterial membrane potential (see, e.g., Baltz, *supra*).

The efficacy and safety of daptomycin has been examined in nonclinical studies and in Phase I and Phase II clinical trials. Daptomycin was well tolerated in human volunteers when given intravenously at 1 or 2 mg/kg every 24 hours. See Baltz, *supra*, and references therein. Furthermore, a single dose of daptomycin was well-tolerated over a dose range of 0.5 to 6 mg/kg. See Baltz, *supra*, and Woodworth et al., 1992, Antimicrob. Agents Chemother. 36:318-25.

However, prolonged treatment with 3 mg/kg daptomycin every 12 hours was shown to cause occasional adverse effects (Baltz, *supra*). Transient muscular weakness and pain were observed in two of five human patients who had been treated with 4 mg/kg daptomycin every 12 hours for 6 to 11 days (Tally, *supra*). In the two subjects who experienced muscular weakness and pain, creatine phosphokinase (CPK) levels had increased one to two days prior to the muscular weakness. Treatment was discontinued three to four days after the initial elevation in CPK was observed. One to two days after discontinuation of daptomycin treatment, CPK levels peaked at levels in excess of 10,000 U/L in one subject and at 20,812 U/L in the second subject (Tally, *supra*). Based upon these studies and the rationale that higher doses of daptomycin were required for efficacy against many types of bacterial infection, clinical studies of daptomycin were discontinued (Baltz, *supra*).

In the above-described clinical trials and in a series of toxicology studies in animals, skeletal muscle was found to be the primary target tissue of daptomycin toxicity. Repeated daily intravenous administration in toxicological studies of high doses of daptomycin in rats and dogs (75 mg/kg/day in rats and 40 mg/kg/day in dogs) caused mild myopathy in the skeletal muscle (Tally, *supra*). It was also found that increases in CPK levels are a sensitive measure of myopathy, and thus can be used to measure daptomycin's effects upon muscle tissue. See Tally et al. *supra*.

Although low doses of daptomycin do not cause muscle toxicity and are effective in treating many gram-positive bacterial infections, certain types of gram-positive bacterial infections, such as deep-seated infections or those caused by certain antibiotic-resistant bacterial strains, may require higher doses of daptomycin for effective treatment. For instance, certain vancomycin-resistant strains of bacteria exhibit a two- to four-fold higher daptomycin minimum inhibitory concentration (MIC) than most vancomycin-susceptible strains. Accordingly, there

is a great need to develop methods for administration of effective amounts of daptomycin that will also minimize adverse skeletal muscle effects.

A non-lipopeptide streptogramin antibiotic combination, quinupristin/dalfopristin, has also shown activity against gram-positive organisms, including antibiotic-resistant bacteria such as methicillin-resistant *Staphylococcus aureus*, glycopeptide intermediary *S. aureus*, and glycopeptide-resistant *Enterococcus faecium* (Rubinstein et al., 1999, J. Antimicrob. Chemother. 44, Topic A, 37-46, hereafter "Rubinstein"). Quinupristin/dalfopristin has been shown to be effective in treatment of nosocomial pneumonia, emergency use studies, complicated skin and skin structure infection and bacteremia (Rubinstein, *supra*). Approximately 13% of the patients treated with 7.5 mg/kg quinupristin/dalfopristin every 8 or 12 hours experienced arthralgia or myalgia, which included muscle pain, and approximately 5% of patients exhibited increased CPK levels (Rubinstein, *supra*). Therefore, it would appear that quinupristin/dalfopristin also causes muscle toxicity

The aminoglycosides, which make up another class of antibiotics, are also toxic at high doses. They have been administered as a high dose at less frequent intervals rather than at lower doses at more frequent intervals in order to reduce their toxicity (Barclay et al., 1994, Clin. Pharmacokinet. 27:32-48). However, aminoglycosides differ from daptomycin in a number of ways, specifically in the fact that the sites of toxicity are distinct. Aminoglycosides are toxic to the kidney and central nervous system whereas skeletal muscle is the site of toxicity for daptomycin. The mechanisms of toxicity for aminoglycosides and daptomycin are also distinct. In addition, aminoglycosides are structurally dissimilar to daptomycin, act only on gram-negative bacteria, have a different mechanism of antibacterial action from daptomycin and exhibit different mechanisms of resistance. Thus, the possibility that less frequent administration of aminoglycosides results in lower toxicity to the patient does not predict that the same would be true for daptomycin.

SUMMARY OF THE INVENTION

The present invention addresses the problem of skeletal muscle toxicity at high doses of lipopeptide antibiotics such as daptomycin, as well as quinupristin/dalfopristin. The invention provides methods for administering the antibiotic that minimizes skeletal muscle toxicity while simultaneously maintaining a sufficient efficacy level.

The process of the invention is characterized by administering less frequent doses comprising a higher concentration of an antibiotic. This protocol is both safer and more efficacious than administering more frequent doses of the antibiotic at lower concentrations. Thus, in one method of the invention, daptomycin is administered to a patient in need thereof at a dosing interval that minimizes skeletal muscle toxicity. In another method of the invention, a lipopeptide antibiotic other than daptomycin, such as a daptomycin derivative, A54145 or a derivative thereof, is administered to a patient in need thereof at a dosing interval that minimizes skeletal muscle toxicity. In a third method of the invention, quinupristin/dalfopristin is administered to a patient in need thereof at a dosing interval that minimizes skeletal muscle toxicity.

The methods of the invention are characterized by administering a high dose of an antibiotic that causes skeletal muscle toxicity at a dosage interval of 24 hours to once weekly. In one embodiment of the invention, daptomycin is administered at a dose of 3 to 75 mg/kg at a dosage interval of 24 hours to once weekly. In another embodiment of the invention, quinupristin/dalfopristin is administered at a dose of 7.5 to 75 mg/kg at a dosage interval of 24 hours to once weekly.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1. Serum creatine phosphokinase (CPK) levels for Dog Study A (top panel) and Dog Study B (bottom panel). Serum CPK levels were

determined at two hours after daptomycin dosing as an indication of muscle toxicity.

Figure 2. Steady state plasma concentrations of daptomycin on day 18 of dosing as determined by HPLC for Dog Study A (top panel) and Dog Study B (bottom panel).

Figure 3. Relationship between different dosing intervals of daptomycin and its skeletal muscle toxicity (related to CPK levels) and its effectiveness (related to the peak serum concentration, C_{max}, over the minimal inhibitory concentration, MIC, of daptomycin).

DETAILED DESCRIPTION OF THE INVENTION

To investigate the potential effects of dose fractionation on toxicity, two studies were conducted in dogs comparing the effects of repeated intravenous administration once daily (q24h) versus every 8 hours (q8h). These studies were conducted in the dog since this species is most predictive of clinical effects. The objective of the studies was to assess the relationship between pharmacokinetics, including C_{max} and AUC_{24h}, and skeletal muscle toxicity, in order to determine the optimal clinical dosing regimen to minimize potential for skeletal muscle toxicity.

Study A explored whether daptomycin-related skeletal muscle toxicity is related to the peak concentration of daptomycin that occurs in the bloodstream after administration (C_{max}) and not to the total concentration of daptomycin in the bloodstream for 24 hours (AUC_{24h}). In Study A, the daptomycin daily dose was fractionated into multiple administrations per day to reduce C_{max} (see Example 1 and Figure 2, top panel).

Study B examined whether a threshold plasma concentration exists for daptomycin-related skeletal muscle toxicity. Under this hypothesis, administration of the no observed effect dose level at 24 hours (NOELq24h) multiple times per day, such that plasma levels of daptomycin remain below some

undetermined threshold of toxicity, would not be associated with skeletal muscle toxicity (Example 2).

Surprisingly, muscle toxicity was not primarily related to C_{max}. For example, both serum creatine phosphokinase (CPK) levels and the incidence of microscopic myopathy observed at 25 mg/kg administered once every 8 hours (q8h) were greater than those observed at 75 mg/kg administered once every 24 hours (q24h), despite the lower C_{max} for 25 mg/kg q8h (Example 1, Table 2). In contrast, large increases in peak CPK levels were observed when the dose interval was varied from q24h to q8h at a dose of either 5 mg/kg or 25 mg/kg even though C_{max} levels were comparable for each dose at either q24h or q8h (Example 1, Table 2 and Example 2, Table 4) Toxicity also did not appear to be related to AUC_{24h}, since the toxicity observed at 25 mg/kg q8h was greater than at 75 mg/kg q24h at approximately the same AUC.

The results of Studies A and B suggest that the pharmacokinetic parameter defining daptomycin-associated skeletal muscle toxicity in dogs is not related to C_{max}. In addition, toxicity did not appear to be related to AUC or an intrinsically toxic plasma concentration, but appeared to be related to the dosing interval of daptomycin. Without wishing to be bound by any theory, skeletal muscle effects appear to be related to the duration of time at low plasma concentrations of daptomycin available for repair of subclinical damage to the myofibers Therefore, the data suggest that the dosing interval is the key determinant of muscle toxicity, rather than just the magnitude of the dose itself. Further, since C_{max} and/or AUC were found to be the key pharmacokinetic parameters associated with eradication of infection (J. Leggett et al., Abstract No. 154, page 123, Program and Abstracts of the 27th Interscience Conference on Antimicrobial Agents and Chemotherapy, American Society for Microbiology, Washington, D.C., 1987; A. Louie et al., Abstract No. 1769, N. Safdar et al., Abstract No. 1770, Program and Abstracts of the 39th Interscience Conference on Antimicrobial Agents and Chemotherapy, American Society for Microbiology, San Francisco, CA, September 26-29,1999),

the pharmacological activity of daptomycin is optimized by once-daily dosing. These results suggest that once-daily dosing can minimize daptomycin muscle toxicity, while potentially optimizing its antimicrobial efficacy (Figure 3).

These observations are further supported by the results of a clinical study. The study demonstrated that daptomycin administered at doses of 4 mg/kg q24h, 6 mg/kg q24h or at an initial dose of 6 mg/kg with subsequent doses at 3 mg/kg q12h did not result in an increase in CPK levels related to daptomycin administration and did not result in any muscle weakness or pain in any patient (Example 4). The C_{max} is predicted to be higher (86.8 μg/mL) at a dose regimen of 6 mg/kg q24h than at a dose regimen of 4 mg/kg q12h (69.2 μg/mL). Yet zero of nine patients tested at the dose regimen predicting a higher C_{max} had drug related adverse skeletal muscle effects (Table 5), whereas two of five patients tested at the dose regimen predicting a lower C_{max} had adverse skeletal muscle effects (Tally, *supra*). Thus, the results presented in Example 3 demonstrate that C_{max} is not the cause of skeletal muscle toxicity in humans, further showing that the findings regarding daptomycin dosing in dogs is applicable to humans.

Without wishing to be being bound by any theory, these results may be explained by the hypothesis that skeletal muscle toxicity is related to time between doses for repair of skeletal muscle damage. For instance, Example 1 demonstrates that CPK levels were much higher when dogs were administered 75 mg/kg/day fractionated into three doses per day (25 mg/kg q8h), than when the same dose was administered once per day (75 mg/kg q24h). Once-daily administration may allow greater time between doses (at non-toxic blood levels) for repair of subclinical muscle damage associated with daptomycin. Thus, once-daily dosing results in less toxicity. The new repair hypothesis is consistent with the lack of progression of toxicity after extended durations of dosing. For instance, there is no progression of toxicity for six-month dosing studies compared to one-month dosing studies in rats and dogs. In addition, the new repair hypothesis is consistent with observations that CPK levels decrease despite continued treatment with

daptomycin and the presence of regenerative changes in skeletal muscle (Figure 1) In addition, because C_{max} and/or AUC are the key determinants of efficacy in animal models of infection, the pharmacological activity of daptomycin is optimized by once-daily dosing. Therefore, because safety and efficacy are not dependent upon the same determinant (C_{max}), the safety margin for daptomycin can be increased by altering the dosing regimen.

Based upon these results, the present invention provides methods for administering daptomycin that minimize skeletal muscle toxicity compared to prior methods for administering daptomycin. The methods may be used for human patients in clinical applications and in veterinary applications. The dose and dosage interval for the method is one that is safe and efficacious in clinical or veterinary applications The method of the invention teaches, in general, that longer dosing intervals can provide for the administration of higher doses of daptomycin.

In one embodiment of the instant invention, the dose is 3 to 75 mg/kg daptomycin. In a preferred embodiment, the dose is 6 to 25 mg/kg. In a more preferred embodiment, the dose for humans patients is 6 to 12 mg/kg. Doses that may be used include 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22 or 25 mg/kg. In a preferred embodiment for veterinary applications, the dose is 3 to 25 mg/kg. Other doses higher than, intermediate to or less than these doses may also be used and may be determined by one skilled in the art following the methods of this invention.

In one embodiment of the instant invention, the dosage interval is 24 hours to once weekly. In a preferred embodiment, daptomycin is administered at a dosage interval of once every 24 hours, once every 48 hours, once every 72 hours, once every 96 hours, or once weekly. Administration at less frequent dosage intervals, such as once every 96 hours or once weekly, may be desirable for patients who have impaired renal function or who require hemodialysis. In a more preferred embodiment the dosage interval is 24 to 48 hours. In an even more preferred embodiment, the dosage interval is 24 hours. The preferred dosage interval for veterinary applications may be somewhat shorter or longer than the preferred

dosage intervals for human patients, depending upon whether daptomycin has a shorter or longer half-life, respectively, in a particular animal species than in humans. The present invention also provides a use of daptomycin for the preparation of medicaments for treating a bacterial infection in a patient at the doses and dosage intervals described herein. Other dosage intervals intermediate to or shorter than these dosage intervals for both clinical and veterinary applications may also be used and may be determined by one skilled in the art following the methods of this invention.

In one embodiment of the invention, the method comprises the step of administering a dose of 3 to 75 mg/kg daptomycin once every 24 hours to once weekly. In a preferred embodiment, daptomycin is administered in a dose of 3 to 25 mg/kg once every 24, 48, 72 or 96 hours. In a more preferred embodiment, daptomycin is administered to a human patient in a dose of 3 to 12 mg/kg every 24 to 48 hours. In an even more preferred embodiment, daptomycin is administered in a dose of 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12 mg/kg once every 24 hours. In veterinary applications, daptomycin is administered in a dose of 3 to 25 mg/kg every 24 hours.

Daptomycin may be administered according to this method until the bacterial infection is eradicated or reduced. In one embodiment, daptomycin is administered for a period of time from 3 days to 6 months. In a preferred embodiment, daptomycin is administered for 7 to 56 days. In a more preferred embodiment, daptomycin is administered for 7 to 28 days. In an even more preferred embodiment, daptomycin is administered for 7 to 14 days. Daptomycin may be administered for a longer or shorter time period if it is so desired.

Furthermore, although the invention has been exemplified using daptomycin, the results and the method of the instant invention are also applicable to other lipopeptide antibiotics and quinupristin/dalfopristin, or other antibiotics that cause skeletal muscle toxicity. Therefore, the present invention also provides methods for administering other lipopeptide antibiotics that minimize skeletal muscle toxicity while maintaining efficacy. The present invention also provides a

use for lipopeptide antibiotics for the preparation of medicaments for treating a bacterial infection in a patient, wherein the dose is a therapeutically effective amount of the lipopeptide antibiotic at a dosage interval that does not result in muscle toxicity. Lipopeptide antibiotics include, without limitation, daptomycin, daptomycin derivatives, and other antibiotics that comprise a proteinaceous domain and a lipid domain, such as A54145 (Baltz, *supra*), or A54145 derivatives.

The present invention also provides methods for administering quinupristin/dalfopristin that minimize skeletal muscle toxicity while maintaining efficacy. The methods may be used for human patients in clinical applications and in veterinary applications. The dose and dosage interval for the method is one that is safe and efficacious in clinical or veterinary applications. The method of the invention teaches, in general, that a higher dose of quinupristin/dalfopristin can be administered by prolonging the dosing interval. In one embodiment, the dose is 7.5 to 75 mg/kg quinupristin/dalfopristin at a dosage interval of 24 hours to once weekly. In a preferred embodiment, the dose is 7.5 to 30 mg/kg. In a more preferred embodiment, the dose for humans patients is 7.5 to 20 mg/kg. In a more preferred embodiment for veterinary applications, the dose is 7 5 to 50 mg/kg. In a preferred embodiment, the dosage interval is 24, 48, 72 or 96 hours. In a more preferred embodiment the dosage interval is 24 hours. The preferred dosage interval for veterinary applications may be somewhat shorter or longer than the preferred dosage intervals for human patients, depending upon whether quinupristin/dalfopristin has a shorter or longer half-life, respectively, in a particular animal species than in humans. The present invention also provides a use for quinupristin/dalfopristin for the preparation of medicaments for treating a bacterial infection in a patient, wherein the dose is a therapeutically effective amount of quinupristin/dalfopristin at a dosage interval that does not result in muscle toxicity.

The methods of the present invention comprise administering daptomycin, other lipopeptide antibiotics or quinupristin/dalfopristin to a patient in need thereof an amount that is efficacious in reducing or eliminating the gram-

positive bacterial infection and that results in reduced skeletal muscle toxicity compared to other methods of administering daptomycin, other lipopeptide antibiotics or quinupristin/dalfopristin. The antibiotic may be administered orally, parenterally, by inhalation, topically, rectally, nasally, buccally, vaginally, or by an implanted reservoir, external pump or catheter. Daptomycin, other lipopeptide antibiotics or quinupristin/dalfopristin also may be directly injected or administered into an abscess, ventricle or joint. Parenteral administration includes subcutaneous, intravenous, intramuscular, intra-articular, intra-synovial, cisternal, intrathecal, intrahepatic, intralesional and intracranial injection or infusion. In a preferred embodiment, the antibiotic administration is via intravenous, subcutaneous or oral administration.

The methods according to the instant invention may be used to treat a patient having a bacterial infection in which the infection is caused or exacerbated by any type of gram-positive bacteria. In a preferred embodiment, daptomycin, a lipopeptide antibiotic or quinupristin/dalfopristin is administered to a patient according to the methods of this invention. In another preferred embodiment, the bacterial infection may be caused or exacerbated by bacteria including, but not limited to, methicillin-susceptible and methicillin-resistant staphylococci (including *Staphylococcus aureus, Staphylococcus epidermidis, Staphylococcus haemolyticus, Staphylococcus hominis, Staphylococcus saprophyticus,* and coagulase-negative staphylococci), glycopeptide intermediary- susceptible *Staphylococcus aureus* (GISA), penicillin-susceptible and penicillin-resistant streptococci (including *Streptococcus pneumoniae, Streptococcus pyogenes, Streptococcus agalactiae, Streptococcus avium, Streptococcus bovis, Streptococcus lactis, Streptococcus sangius* and *Streptococci* Group C, *Streptococci* Group G and viridans streptococci), enterococci (including vancomycin-susceptible and vancomycin-resistant strains such as *Enterococcus faecalis* and *Enterococcus faecium*), *Clostridium difficile*, *Clostridium clostridiiforme*, *Clostridium innocuum*, *Clostridium perfringens*, *Clostridium ramosum, Haemophilus influenzae, Listeria*

monocytogenes, Corynebacterium jeikeium, Bifidobacterium spp., *Eubacterium aerofaciens, Eubacterium lentum, Lactobacillus acidophilus, Lactobacillus casei, Lactobacilllus plantarum, Lactococcus* spp., *Leuconostoc* spp., *Pediococcus, Peptostreptococcus anaerobius, Peptostreptococcus asaccarolyticus, Peptostreptococcus magnus, Peptostreptococcus micros, Peptostreptococcus prevotii, Peptostreptococcus productus, Propionibacterium acnes,* and *Actinomyces* spp.

The antibacterial activity of daptomycin against classically "resistant" strains is comparable to that against classically "susceptible" strains in *in vitro* experiments. In addition, the minimum inhibitory concentration (MIC) value for daptomycin against susceptible strains is typically 4-fold lower than that of vancomycin. Thus, in a preferred embodiment, daptomycin is administered according to the methods of this invention to a patient who exhibits a bacterial infection that is resistant to other antibiotics, including vancomycin. In addition, unlike glycopeptide antibiotics, daptomycin exhibits rapid, concentration-dependent bactericidal activity against gram-positive organisms. Thus, in a preferred embodiment, daptomycin is administered according to the methods of this invention to a patient in need of rapidly acting antibiotic therapy. Quinupristin/dalfopristin is also useful for treating antibiotic-resistant strains of bacteria, and may be used in emergency use situations.

The methods of the instant invention may be used for a gram-positive bacterial infection of any organ or tissue in the body. These organs or tissue include, without limitation, skeletal muscle, skin, bloodstream, kidneys, heart, lung and bone. The methods of the invention may be used to treat, without limitation, skin and soft tissue infections, bacteremia and urinary tract infections. The methods of the invention may be used to treat community acquired respiratory infections, including, without limitation, otitis media, sinusitis, chronic bronchitis and pneumonia, including pneumonia caused by drug-resistant *Streptoococcus pneumoniae* or *Haemophilus influenzae*. The methods of the invention may be

used to treat mixed infections that comprise different types of gram-positive bacteria, or which comprise both gram-positive and gram-negative bacteria These types of infections include intra-abdominal infections and obstetrical/gynecological infections. The methods of the invention may be used in step down therapy for hospital infections, including, without limitation, pneumonia, intra-abdominal sepsis, skin and soft tissue infections and bone and joint infections. The methods of the invention also may be used to treat an infection including, without limitation, endocarditis, septic arthritis and osteomyelitis. In a preferred embodiment, any of the above-described diseases may be treated using daptomycin according to the methods of the instant invention. In another preferred embodiment, any of the above-described diseases may be treated using a lipopeptide antibiotic or quinupristin/dalfopristin according to the methods of the instant invention.

The methods of the instant invention may also be practiced while concurrently administering one or more antibiotics other than a lipopeptide antibiotic. Daptomycin exhibits high plasma protein binding and is unable to cross cell membranes. Thus, daptomycin and other lipopeptide antibiotics that exhibit these characteristics are unlikely to cause interactions with other antibiotics. Given this profile, daptomycin would be expected to work synergistically with one or more co-administered antibiotics. Furthermore, daptomycin may improve the toxicity profile of one or more co-administered antibiotics. It has been shown that administration of daptomycin and an aminoglycoside may ameliorate renal toxicity caused by the aminoglycoside. Quinupristin/dalfopristin may also be administered according to this invention with certain other antibiotics. Quinupristin/dalfopristin inhibits cytochrome P450 3A4-mediated metabolism of certain drugs, such as midazolam, nifedipine, terfenadine and cyclosporin, so these drugs should not be co-adminstered with quinupristin/dalfopristin. In a preferred embodiment, an antibiotic may be administered concurrently while practicing the method of this invention Antibiotics and classes thereof that may be co-administered with daptomycin or another lipopeptide antibiotic include, without limitation, penicillins

and related drugs, carbapenems, cephalosporins and related drugs, aminoglycosides, bacitracin, gramicidin, mupirocin, chloramphenicol, thiamphenicol, fusidate sodium, lincomycin, clindamycin, macrolides, novobiocin, polymyxins, rifamycins, spectinomycin, tetracyclines, vancomycin, teicoplanin, streptogramins, anti-folate agents including sulfonamides, trimethoprim and its combinations and pyrimethamine, synthetic antibacterials including nitrofurans, methenamine mandelate and methenamine hippurate, nitroimidazoles, quinolones, fluoroquinolones, isoniazid, ethambutol, pyrazinamide, para-aminosalicylic acid (PAS), cycloserine, capreomycin, ethionamide, prothionamide, thiacetazone and viomycin. In a preferred embodiment, antibiotics that may be co-administered with daptomycin or other lipopeptide antibiotics according this invention include, without limitation, imipenen, amikacin, netilmicin, fosfomycin, gentamicin, ceftriaxone and teicoplanin.

EXAMPLE 1

<u>STUDY A:</u> <u>EFFECT OF C_{MAX} ON CPK AND SKELETAL MUSCLE TOXICITY</u>

In order to study the effects of C_{max} on skeletal muscle toxicity, dogs (4 male dogs/group) were administered dose regimens of saline q8h, daptomycin 25 mg/kg q24h, daptomycin 75 mg/kg q24h and daptomycin 25 mg/kg q8h intravenously for 20 days. Skeletal muscle toxicity was measured in dogs by increases in CPK levels to above the normal range and by microscopic changes in skeletal tissue.

Steady state plasma concentrations of daptomycin on day 18 of dosing were determined by HPLC. C_{max} levels were approximately the same (1.23-fold higher) at 25 mg/kg q8h compared to 25 mg/kg q24h. C_{max} levels were approximately 2.8-fold higher at 75 mg/kg q24h compared to 25 mg/kg q8h. See Figure 1, top panel (Study A). The AUC was approximately the same (0.37-fold

higher) at 25 mg/kg q8h compared to 75 mg/kg q24h (see Table 2 and Figure 2, top panel).

Throughout the treatment period in Study A, a dose-proportional increase in peak CPK activity was apparent when the dose was increased from 25 to 75 mg/kg at a constant q24h dosing interval. However, an additional 4-fold increase in CPK levels were observed in animals dosed at 25 mg/kg q8h as compared with those dosed at 75 mg/kg q24h, even though the total daily dose for these two regimens was the same. For all dose regimens, CPK peaked after approximately 1 week of treatment, then declined despite continued treatment.

Treated animals were sacrificed at approximately one dosing interval after the last dose and muscle tissue was microscopically examined for indications of myopathy. See Table 1.

TABLE 1

	Dose Regimen			
Site Lesion*	**Saline q8h**	**25 mg/kg q24h**	**75 mg/kg q24h**	**25 mg/kg q8h**
Skeletal muscle				
Myofiber degeneration	0/24	3/24	8/24	14/24
Myofiber regeneration	1/24	2/24	1/24	9/24
Diaphragm				
Myofiber degeneration	0/4	0/4	0/4	1/4
Heart				
Myofiber degeneration	0/4	0/4	0/4	0/4

* The incidence of muscle-related histopathological findings is presented as the number of sites affected divided by the number of sites examined. For skeletal muscle, six sites were examined in each of four dogs for a total of 24 sites.

Skeletal myofiber degeneration increased approximately two-fold at 25 mg/kg q8h compared to 75 mg/kg q75h. In addition, skeletal myofiber degeneration increase five-fold at 25 mg/kg q8h compared to 25 mg/kg q24h. The skeletal myofiber degeneration was of minimal severity, correlating to three- to 25-

fold increases in serum CPK. No microscopic degenerative effect on heart muscle was observed in Study A.

The findings of Study A are summarized in Table 2:

TABLE 2

Dose Regimen	Total Daily Dose (mg/kg)	C_{max} (µg/mL)	$AUC_{0\text{-}24h}$ (µg-h/mL)	Peak CPK (U/L)	Incidence of Micro-scopic Myopathy[1]
saline q8h	0	0	0	265	0/28
25 mg/kg q24h	25	190	682	309*	3/28
75 mg/kg q24h	75	540	1840	990	8/28
25 mg/kg q8h	75	238	2526	4000	15/28

* Outlier excluded.

[1] The incidence of microscopic myopathy (last column) shows the number of sites that exhibit minimal degenerative changes divided by the number of sites examined. In this experiment, seven sites were examined in each of four dogs for a total of 28 sites.

In addition, toxicity did not appear to be related to $AUC_{0\text{-}24h}$ or a nontoxic plasma concentration threshold. Increases in CPK and incidence of myopathy were greater at 25 mg/kg q8h than at 75 mg/kg q24h despite the lower C_{max}. Further, there was a 5-fold increase in toxicity as measured by the incidence of microscopic myopathy and a greater than 10-fold increase in CPK levels when 25 mg/kg was administered three times a day compared to once daily despite comparable C_{max} levels. Although the AUC was only 0.37-fold higher at a dose regimen of 25 mg/kg q8h as compared to 75 mg/kg q24h, CPK activity and incidence of myopathy increased 2- to 4-fold.

Without wishing to be bound by any theory, skeletal muscle effects appear to be related to the duration of time at low plasma concentrations available for repair of subclinical damage to the myofibers. In comparison to dose fractionation, once-daily dosing resulted in greater time at minimal plasma

concentrations, allowing for more time for repair and, therefore, less toxicity For example, at a dose regiment of 25 mg/kg q8h, the plasma concentrations never fell below 27 μg/mL, the trough value for this regimen. In contrast, plasma concentrations for the 75 mg/kg q24h regimen were below this level for approximately 12 hours prior to administration of the next dose. This daily period of minimal exposure may explain why the once-daily dosing regimen (75 mg/kg q24h) was associated with less toxicity than fractionated dosing (25 mg/kg q8h)

EXAMPLE 2

STUDY B: EFFECT OF THRESHOLD PLASMA CONCENTRATION ON SKELETAL MUSCLE TOXICITY

In order to study the effects of threshold plasma concentration on skeletal muscle toxicity, dogs (4 male dogs/group) were administered dose regimens of saline q8h, daptomycin 5 mg/kg q24h (approximate NOELq24h) and daptomycin 5 mg/kg q8h intravenously for 20 days.

As in Example 1, steady state plasma concentrations of daptomycin on day 18 of dosing were determined by HPLC. The q8h interval represents 3 half-lives in dogs ($t_{1/2}$ = 2.5 hours) and should have minimal impact on steady state C_{max} as compared to a q24h regimen. The C_{max} for 5 mg/kg q8h and 5 mg/kg q24h was approximately the same for both dose regimens. See Figure 1, bottom panel (Study B). However, the AUC was approximately three-fold higher (2.6-fold higher) at 5 mg/kg q8h compared to 5 mg/kg q24h (see Table 4 and Figure 2, bottom panel).

Serum CPK levels were determined as disclosed in Example 1. There were no changes in CPK levels at 5 mg/kg q24h compared to the saline control. In contrast, CPK levels at 5 mg/kg q8h were elevated compared to 5 mg/kg q24h or saline controls. At 5 mg/kg q8h, CPK levels peaked at levels three- to four-fold higher than baseline after one week of daptomycin treatment, and declined thereafter despite continued treatment, similar to what was seen in Study A See Figure 1, bottom panel (Study B).

Treated animals were sacrificed at approximately one dosing interval after the last dose and muscle tissue was examined microscopically for indications of myopathy as in Example 1, shown in Table 3.

TABLE 3

	Dose Regimen		
Site **Lesion***	**Saline q8h**	**5 mg/kg q24h**	**5 mg/kg q8h**
Skeletal muscle			
Myofiber degeneration	0/24	2/24	11/24
Myofiber regeneration	0/24	3/24	18/24
Diaphragm			
Myofiber degeneration	0/4	1/4	0/4
Heart			
Myofiber degeneration	0/4	0/4	0/4

* The incidence of muscle-related histopathological findings is presented as the number of sites affected divided by the number of sites examined. For skeletal muscle, six sites were examined in each of four dogs for a total of 24 sites.

Skeletal myofiber degeneration increased four-fold at 5 mg/kg q8h compared to 5 mg/kg q24h. Degeneration was of very minimal severity with very few fibers affected, correlating with zero- to four-fold increases in CPK levels. The myofiber degeneration was less severe in Study B than at the higher doses used in Study A. No degenerative effect on heart muscle was observed in Study B.

The findings of Study B are summarized in Table 4:

TABLE 4

Dose Regimen	Total Daily Dose (mg/kg)	C_{max} (µg/mL)	AUC_{0-24h} (µg-h/mL)	Peak CPK (U/L)	Incidence of Micro-scopic Myopathy[1]
saline q8h	0	0	0	150	0/28
5 mg/kg q24h	5	58	180	150	3/28
5 mg/kg q8h	15	58	412	500	11/28

[1] The incidence of microscopic myopathy (last column) shows the number of sites that exhibit minimal degenerative changes divided by the number of sites examined. In this experiment, seven sites were examined in each of four dogs for a total of 28 sites.

At a q24h dosing interval, the NOEL is approximately 5 mg/kg. This NOELq24h results in no CPK changes and only very minimal histopathological evidence of skeletal muscle toxicity. However, these experiments demonstrate that the NOELq24h does not define a threshold plasma concentration for toxicity because administration every 8 hours (i.e., 5 mg/kg q8h) leads to skeletal muscle toxicity evident by increases in CPK and microscopic myopathy even though the C_{max} was similar to that of the 5 mg/kg q24h regimen. Toxicity may be related to time below a given plasma concentration. For example, time below 10 µg/mL is 6 hours at 5 mg/kg q8h compared to 18 hours at 5 mg/kg q24h. See Figure 1, bottom panel. These results suggest that the peak plasma concentration of daptomycin associated with no observable skeletal muscle toxicity is dependent upon dosing frequency.

EXAMPLE 3

In order to study the effects of C_{max} of quinupristin/dalfopristin on skeletal muscle toxicity, dogs (4 male dogs/group) are administered dose regimens

of saline q8h, quinupristin/dalfopristin 25 mg/kg q24h, quinupristin/dalfopristin 75 mg/kg q24h and quinupristin/dalfopristin 25 mg/kg q8h intravenously for 20 days.

Steady state plasma concentrations of quinupristin/dalfopristin on day 18 of dosing are determined by HPLC. C_{max} levels and AUC are measured as described in Example 1 for 25 mg/kg q8h, 25 mg/kg q24h and 75 mg/kg q24h. Similarly, CPK levels and the incidence of muscle-related histopathological findings are determined as described in Example 1 for 25 mg/kg q8h, 25 mg/kg q24h and 75 mg/kg q24h. For skeletal muscle, six sites are examined in each of four dogs for a total of 24 sites. If no microscopic myopathy or effects on CPK levels are observed at any of the dose regimens, then the doses may be increased. For instance, C_{max} levels and AUC may be measured for 50 mg/kg q8h, 50 mg/kg q24h and 150 mg/kg q24h.

A dosage regimen of 25 mg/kg quinupristin/dalfopristin q8h is expected to result in greater muscle toxicity, as measured by elevated CPK levels and/or a greater incidence of microscopic myopathy, than a dosage regimen of 75 mg/kg quinupristin/dalfopristin q24h. However, C_{max} levels are expected to be higher for 75 mg/kg q24h than C_{max} levels for 25 mg/kg q8h and thus will result in greater efficacy at 75 mg/kg quinupristin/dalfopristin q24h than 25 mg/kg quinupristin/dalfopristin q8h.

EXAMPLE 4

In order to study whether an increased dosing interval would prevent transient skeletal muscle toxicity in patients, daptomycin was administered intravenously to hospitalized adult subjects with serious gram-positive bacteremia or with a variety of infections due to gram-positive bacteria that was resistant to vancomycin or who were otherwise refractory to, or contraindicated for, currently available therapy. The subjects were treated for a period of 7-21 days. Serum CPK levels were determined prior to first antibiotic treatment and every other day for the first seven days of treatment, and daily thereafter.

The results demonstrate that administration of daptomycin to eight patients at a 4 mg/kg dose every 24 hours or to nine patients at a 6 mg/kg dose every 24 hours did not cause an increase in serum CPK levels above the normal range (20-198 U/L) in a majority of patients. See Table 5. Furthermore, even in the few patients who experienced some elevation in CPK levels above normal, the elevation was not considered to be related to daptomycin treatment. None of the patients experienced any muscular pain or weakness and all patients were able to finish the course of daptomycin treatment. Similarly, administration of an initial dose of 6 mg/kg daptomycin followed by 3 mg/kg every 12 hours to three human patients did not cause an increase in CPK levels above normal.

Table 5

Patient	Pre-dose baseline	CPK Range[1] of Observations During Treatment		Total Number of Patients with Presumed Drug-Related Adverse Skeletal Muscle Effects[2]/ Total Evaluated
		Minimum	Maximum	
6MG/KG q 24h				
1	<18	<18	194	0/9
2	129	54	140	
3	NA	<18	56	
4	35	<18	43	
5	<18	<18	<18	
6	44	<18	44	
7	11	6	101	
8	25	8	25	
9	284	171	*1324	
4 MG/KG q 24h				
1	43	33	59	0/8
2	18	18	35	
3	25	19	212	
4	44	<18	48	
5	144	<18	144	
6	23	20	36	
7	37	32	369**	
8	<18	<18	26	
6 MG/KG followed by 3 MG/KG q 12h				
1	78	78	137	0/3
2	29	<18	49	
3	<18	<18	34	

1 Normal CPK range 20-192; detectable level 18.

2 CPK > ULN (192 U/L) and with accompanying clinical signs of pain/weakness or CPK > ULN (192 U/L) without accompanying clinical signs of pain/weakness and with no underlying cause for increased CPK levels.

* Increase in CPK began after 1st dose; returned to baseline while continuing daptomycin treatment. Patient also receiving steroid treatment.

** Value occurred after the 13th dose and returned to baseline with continued treatment.

EXAMPLE 5

Different dosage levels at various dosage intervals of daptomycin are administered to human subjects. Daptomycin is administered intravenously to adult subjects with a diagnosis of an infection due to a gram-positive bacteria strain that is resistant to vancomycin or who are otherwise refractory to, or contraindicated for, currently available therapy. The subjects are treated for a period of 7 to 14 days The treatment may be extended to 28 to 56 days. Different doses of daptomycin are administered at a dosage interval of once every 24 hours, once every 48 hours, once every 72 hours, once every 96 hours, or once weekly. Other dosage intervals intermediate to or shorter than these dosage intervals may also be used. Dosage levels that may be used include 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22 or 25 mg/kg. Other dosage levels that are lower than, intermediate to, or higher than these dosage levels also may be used. The efficacy of the treatment is measured by one or more of the following criteria: eradication or reduction of the gram-positive bacteria blood concentrations that are isolated at admission to the study by microbiological measures; the time in days to microbiological resolution or improvement of the bacterial infection; resolution or improvement of clinical signs and symptoms reported at admission; and survival rates at 3 to 4 weeks after the last dose of antibiotic. A dosage level and interval is efficacious when one or more of the above criteria is satisfied. Serum CPK levels were determined prior to first antibiotic treatment and every other day for the first seven days of treatment, and daily thereafter. A dosage level and interval is safe when it does not cause serum CPK levels to rise significantly above normal levels or when the treatment does not cause skeletal muscular pain or weakness.

EXAMPLE 6

The procedures described in Example 5 are followed essentially as described except that quinupristin/dalfopristin is administered to a patient instead of daptomycin, and the dosage levels range from 7.5 to 30 mg/kg q24h. Dosage levels

that may be used include 7.5, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28 or 30 mg/kg. Other dosage levels that are lower than, intermediate to, or higher than these dosage levels also may be used.

All publications and patent applications cited in this specification are herein incorporated by reference as if each individual publication or patent application were specifically and individually indicated to be incorporated by reference. Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it will be readily apparent to those of ordinary skill in the art in light of the teachings of this invention that certain changes and modifications may be made thereto without departing from the spirit or scope of the appended claims.